Structure and Properties of Atoms

PS-2 The student will demonstrate an understanding of the structure and properties of atoms.

PS-2.1 Compare the subatomic particles (protons, neutrons, electrons) of an atom with regard to mass, location, and charge, and explain how these particles affect the properties of an atom (including identity, mass, volume, and reactivity).

Taxonomy Level: 2.6-B Understand Conceptual Knowledge
2.7-B Understand Conceptual Knowledge

Key Concepts:

Sub-atomic particles: proton, neutron, electron
Energy level
Electron Cloud
Nucleus

Previous/Future knowledge: In 7th grade, students recognize that matter is composed of tiny "particles called atoms" (7-5.1). Students have no prior knowledge about the structure of the atom. In Physical Science, students identify and compare the *sub*atomic particles that compose atoms and develop a fundamental concept of the role that these three particles have in determining the properties of the atoms that they compose. The concepts addressed in this indicator are the foundation for the Atomic Theory, the idea that the physical and chemical properties of substances are functions of the particles of which they are composed, and are, therefore, prerequisite for PS-3 (properties of matter), PS-4 (chemical reactivity) and all subsequent study of chemistry.
This is an introduction so it is essential to emphasize a concrete, descriptive approach.

It is essential for students to compare subatomic particles by

- **Particle type**:
  - Know that the atom is composed of *subatomic particles* (*protons*, *neutrons*, and *electrons*) that affect the properties of an atom.
- **Particle mass**:
  - Understand that protons and neutrons have about the same mass.
  - Understand that the mass of an electron is much less than the mass of protons and neutrons (It is not necessary for students to know the exact mass of the particles).
- **Particle charge**:
  - Understand that protons have a positive charge; know that neutrons have no charge.
  - Understand that the net charge of the nucleus is positive and equal to the number of protons.
  - Understand that electrons have a negative charge.
  - Understand that there is an attractive force between negative electrons and positive protons (unlike charges attract).
  - Understand that there is a repulsive force between electrons and electrons, and between protons and protons (like charges repel).
  - Understand that atoms are neutrally charged when the number of electrons is the same as the number of protons.
- **Particle location**:
  - Understand that protons and neutrons are tightly bound in a tiny *nucleus*.
  - Understand that the nucleus is located in the center of the atom with the electrons moving in complicated patterns in the space around the nucleus.

- Understand that the electrons have energy and that as the level of energy (*the energy level*) of an electron increases, the electron is likely to (will probably) spend more time further from the nucleus.
- Understand that the total region in space where electrons are likely to be found around the nucleus of an atom is often called the 'electron cloud'.
- Understand that as the *energy levels* of electrons increase, the regions of space where the electrons are likely to be found are at increasing distances from the nucleus.
- Electrons with more energy occupy higher energy levels and are likely to be found further from the nucleus.
  - There are a maximum number of electrons that can occupy each energy level and that number increases the further the energy level is from the nucleus.

It is not essential for students to

- Know the exact number of electrons that can occupy each energy level.
- Know that the main energy level occupied by an electron is a description of the principal quantum number.
- Understand the nature of the other quantum numbers (angular momentum quantum number, magnetic quantum number, or spin quantum number).
- Understand the forces holding the nucleus together.

It is essential that students understand the role that subatomic particles have in determining the properties of atoms:

- **Identity of the Atom**:
  - Understand that the number of protons determines the identity of an atom (an element).
  - Understand that while atoms of the same element have the same number of protons, the number of neutrons may vary (PS-2.2).
  - Understand that an atom of a given element may lose or gain electrons yet it still remains the same element.
- **Mass of the Atom**:
  - Understand that the total number of protons and neutrons within its nucleus is a major determinant for the mass of the atom, because the mass of the atom's electrons is insignificant by comparison.
- **Reactivity of the Atom**:
  - The particles in the nucleus of the atom do not change in a chemical reaction.
  - Chemical reactions occur because the electrons around the atoms are exchanged or shared. The number of electrons in the outer energy level of the atom and the relative distance from the nucleus of these outer-energy level electrons determine how the atom will react chemically.
- **Volume of the Atom**:
  - The volume of the 'electron cloud' determines the volume of the atom. The volume of the nucleus of a typical atom is extremely small when compared to the volume of space occupied by the atom's electrons.

It is not essential for students to

- Understand the contributions of shielding effect and nuclear attraction to atomic radius.

Structure and Properties of Atoms

PS-2 The student will demonstrate an understanding of the structure and properties of atoms.

Misconception: (Teacher note)

Most students have the misconception that an atom is like the diagrams in their textbooks: a nucleus roughly half the size of the atom, electrons orbiting in perfect circles. Students need to understand that this is a convenient way to represent the parts an atom, but not a dimensionally accurate representation. A drawing such as the one below also gives students the incorrect impression that electrons orbit the nucleus in regular, circular paths.

It is important that students can visualize the nucleus of an atom as a tiny speck in the center of an atom and the electron cloud as an area outside the nucleus where electrons are moving erratically like bees around a beehive. The electrons with more energy can move further from the nucleus, those with less energy stay closer. The space where the electrons are moving makes up the vast majority of the volume of the atom.

In order to visualize the perspective, if the nucleus of an atom is represented by a speck the size of the period at the end of this sentence, the first electrons are likely to be found in a region at a distance away from the speck equal to the length of a football field.

Assessment Guidelines:

The first objective of the indicator is to *compare* the three primary subatomic particles with regard to mass, charge and location; therefore the primary focus of assessment should be to detect correspondences between and among these particles with regard to these three properties.

In addition to *compare*, assessment may require students to

- *Illustrate* with drawings or diagrams that depict the charge, and mass of the three particles;
- *Classify* the three particles based on the characteristics of mass, location, and charge;
- *Summarize* the characteristics of the subatomic particles;
- *Identify* the charge of each particle, the charge of the nucleus, and the charge of the electron cloud;
- *Recognize* that protons and neutrons are located in the nucleus and electrons in the electron cloud;
- *Recall* that the nucleus is a densely packed core and the electron cloud as an area of vast space by comparison.

The 2nd objective of the indicator is to *explain* the role that the three primary subatomic particles have in determining the mass of the atom, the volume of the atom, the identity of the atom and how the atom is likely to react chemically, therefore, the primary focus of assessment should be to construct a cause and effect model of the role that each sub-atomic particle plays in determining the properties and characteristics of atoms.

In addition to *explain*, assessment may require students to

- *Infer* how each characteristic (identity, mass, volume, and or reactivity of an atom) would be affected if the number of particles changed;
- *Summarize* the significance of each subatomic particle in determining the atom's characteristics;
- *Recognize* the role that each particle has in the characteristics of an atom.

Structure and Properties of Atoms

PS-2 The student will demonstrate an understanding of the structure and properties of atoms.

PS-2.2 Illustrate the fact that the atoms of elements exist as stable or unstable isotopes.
Taxonomy Level: 2.2-B Understand Conceptual Knowledge

Key Concepts:
atomic number nuclear decay
mass number radiation
isotope
atomic mass

Previous/Future knowledge: In 7th grade, students recognize that matter is composed of tiny "particles called atoms" (7-5.1). Students have no prior learning about isotopes or atoms being stable or unstable.
In Physical Science PS-2.1, students identify and compare the *sub*atomic particles that compose atoms and develop a fundamental concept of the role that these three particles have in determining the properties of the atoms that they compose. This indicator (PS-2.2) expands on how the number of neutrons affects the properties of an atom. Students are introduced to the concept of isotopes and to the idea that the nucleus those isotopes can be stable or unstable. The concept of isotopes as stable or unstable is the basis for an understanding of nuclear reactions. Indicators PS-2.6 and PS-2.7 expand on nuclear reactions. Subsequent chemistry courses will further explore nuclear processes and reactions.

It is essential for students to understand

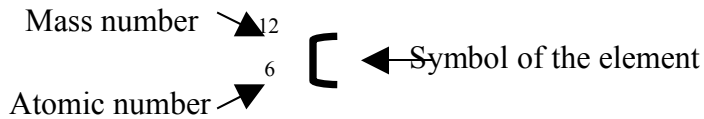
- **Atomic Number**:
  - The *atomic number* of an element is equal to the number of protons. The atomic number is always the same for a given element.
  - The atomic number of an element can be found on the periodic table. It is a whole number since it is equal to the number of protons in the nucleus of the atom and is, therefore, the same for all atoms of that element.
- **Mass Number**:
  - Atoms of the same element may have different numbers of neutrons.
  - The *mass number* of a particular atom is the sum of that atom's protons and neutrons.
  - The mass number cannot be found on the periodic table. (The mass number is not the same as atomic mass and **cannot** be found by rounding off the atomic mass. The mass number must be given through words or a symbol.)
- **Isotopes**:
  - Atoms of the same element with different numbers of neutrons will have different mass numbers.
  - *Isotopes* are defined as two or more atoms of the same element having the same number of protons but different numbers of neutrons (and therefore different masses)
- **Atomic Mass**:
  - The *atomic mass* of an element is the weighted average of the masses of the naturally occurring isotopes of an element.
  - The atomic mass of an element can be found on the periodic table. Since the atomic mass of an element is an average, it is usually not a whole number.

Structure and Properties of Atoms

PS-2 The student will demonstrate an understanding of the structure and properties of atoms.

Students must be able to

- *Illustrate* isotopes (or recognize illustrations of isotopes) with diagrams, symbols, or with words; in each case, the illustration must indicate that isotopes are atoms with the same number of protons, but different numbers of neutrons.
  - The following are two widely accepted examples of symbols used to illustrate one isotope of carbon:



  - It is important that students are familiar enough with the meaning of each of these symbols that they can recognize each, not by position but by logic. (See PS-2.3)
- Understand isotopes with unstable nuclei:
  - In order for a nucleus to be stable, a correct ratio of neutrons and protons should be present in the nucleus.
  - An isotope with an unstable nucleus is radioactive.
  - Due to the unstable condition of the nucleus, radioactive isotopes undergo nuclear decay.
    - *Nuclear decay* is a nuclear reaction that involves emission of energy and/or particles from the nucleus, resulting in a more stable nuclear environment.
    - *Radiation* is the term used to describe the particles and/or energy that are emitted during nuclear decay. (Three types are alpha and beta particles, and gamma rays)
    - Nuclear decay occurs naturally in many elements that are common on earth and there is always some radiation present in every environment.
      (See indicator PS-2.7 for the effects of nuclear radiation.)
- Use a periodic table to apply these concepts to describe any atom given enough information. For example, given the symbol of an element, with mass number and atomic number, the student should be able to give the number of each of the basic particles (protons, neutrons, electrons) in the neutral atom of any element. The periodic table (revised August 2007) that students will use on the end-of-course test should be downloaded from the following website (see PS-2.3):

http://ed.sc.gov/agency/offices/assessment/programs/endofcourse/documents/periodtablerevised08_14_07.pdf

Misconception: (Teacher note)
Students often confuse the mass number of a given isotope with the atomic mass of the element. It is important to emphasize that the mass number of a specific isotope of an element must be given to the student in order to calculate the number of neutrons. Students often have the misconception that the mass number of a given isotope of an element can be determined by rounding the atomic mass of the element (found on the periodic table).

Structure and Properties of Atoms

PS-2 The student will demonstrate an understanding of the structure and properties of atoms.

It is not essential for students to

- Memorize the mass number, atomic number or symbol of any element;
- Understand the reasons that some isotopes are unstable;
- Understand the types of nuclear radiation (alpha, beta, or gamma);
- Balance nuclear equations;
- Understand half-life;
- Compare the strong nuclear force and electrostatic force; or
- Determine whether a specific isotope is stable or unstable.

Assessment Guidelines:

The objective of this indicator is to *illustrate* that atoms exist as stable or unstable isotopes; therefore the primary focus of assessment should be to give or use illustrations (descriptions, diagrams, or symbols) of these concepts to show understanding of isotopes. Assessments should test the student's ability to apply this concept to any element, not be restricted to memorized examples. Students should know that some isotopes have nuclei that are "unstable" should have an understanding of nuclear decay as a result of an unstable nucleus, and understand that radiation is a result of nuclear decay.

In addition to *illustrate*, assessments may require students to

- *Interpret* (change from one form of representation to another), for instance, read a written description of an isotope and produce an illustration in the form of a symbol or a diagram;
- *Compare* stable and unstable isotopes;
- *Recognize* isotopes of the same element.

Structure and Properties of Atoms

PS-2 The student will demonstrate an understanding of the structure and properties of atoms.

PS-2.3 Explain the trends of the periodic table based on the elements' valence electrons and atomic numbers.

Taxonomy Level: 2.7-B Understand Conceptual Knowledge

Key Concepts:

Periodic table organization: period, group or family
metal, nonmetal, metalloid
atomic number, atomic mass
valence electron

As periodic tables vary greatly both in format and in the information which they provide, it is very important that students are comfortable using the periodic table that will be available on the End-of-Course Test. Each student should receive a copy of this periodic table (revised August 2007) at the beginning of the physical science course and be encouraged to use it for **all** homework, class-work, and assessments. The periodic table can be downloaded from the following website:
http://ed.sc.gov/agency/offices/assessment/programs/endofcourse/documents/periodtablerevised08_14_07.pdf

Previous/Future knowledge: Students were introduced to the basic organization of elements on the periodic table in the 7th grade (7-5.4). The concepts addressed in this Physical Science indicator will develop an understanding of how the periodic table can be used to discern an element's atomic structure as well as an understanding of how an element's position on the periodic table can be used to predict how it will bond, its chemical reactivity, and its chemical properties (PS-2.5 and PS-4.1 through PS4.10). Students should understand the reasons for the trends and therefore use logic to describe them. The periodic table is a valuable tool used by chemistry students from high school through college and in the workplace. With each subsequent chemistry course, students will learn more information that can be determined by the element's position on the periodic table.

It is essential for student to

- Understand the parts of the periodic table in order to understand trends
- Know that *period* is the term used to describe a horizontal row on the periodic table.
- Know that *Group* and *Family* are terms used to describe a vertical column on the periodic table.
- Locate major categories of elements such as the *metals*, *metalloids*, and *nonmetals* (metals and nonmetals were introduced in 7th grade).
  - *Metalloids* should be identified as elements that have some characteristics of metals and some of nonmetals; they border the line between metals and nonmetals on the periodic table.
- Locate referenced elements when prompted with a period number or group number.
- Determine a given element's *atomic number* (number of protons).
- Determine the number of electrons that an atom of a given element contains (the same as the number of protons, i.e., its atomic number).
- Determine how many energy levels are occupied in a given element by recognizing that the period in which an element appears on the periodic table indicates the number of occupied energy levels.
  - For example, all elements in period 4 have four occupied energy levels.
  - This is an introduction to quantum theory that will be studied in chemistry.
- Recognize a given element's *atomic mass* (the weighted average of the masses of the naturally occurring isotopes of the element), by recognizing that the atomic mass of an element is a decimal

number. It is always larger than the atomic number and generally increases for each successive element

- Determine the number of *valence electrons* (electrons in the outer-most energy level) for selected groups of elements when given the element's group number or name.
  - Elements in groups 1-2, 13-18

Group or Family	**Name**	**# valence electrons**
1	Alkali metals	1
2	Alkaline Earth Metals	2
13		3
14		4
15		5
16	Oxygen group	6
17	Halogens	7
18	Noble Gases	8 (except He)

It is essential that students

- Understand some of the trends in the properties of the elements that the periodic table displays.
  - Periodic trends in the number of valence electrons:
    - From left to right ***across periods 1-3:*** (Not from left to right across periods 4-7 as a deeper understanding of quantum theory is prerequisite for understanding these trends.
      - Atoms of all these elements contain one more valence electron than the atoms of the previous element.
    - From top to bottom within any group:
      - Atoms of all of the elements in a given group contain the same number of valence electrons.
  - Periodic trends in the number of energy levels:
    - From left to right across any period:
      - Atoms of all elements in a given period have the same number of energy levels.
    - From top to bottom within any group
      - Atoms of each subsequent element (from top to bottom) in any given group contain one more energy level than the atoms of the element above.
- Use knowledge of those trends to predict properties of elements relative to each other (not specific values, but given two elements, determine which element will have the higher value for each of the trends listed above).

It is not essential for students to

- Recall the history of the periodic table although the history of the periodic table highlights its purpose and, therefore, would serve as a definite aide in helping students comprehend the value and relevance of this concept;
- Understand the carbon-12 standard for atomic mass;
- Calculate a weighted average;

Structure and Properties of Atoms

PS-2 The student will demonstrate an understanding of the structure and properties of atoms.

- Determine the number of valence electrons for the Transition Elements, elements in groups 3-12 (including the Lanthanide Series and the Actinide Series) as the transition elements have various numbers of valence electrons depending upon the stability of their "d" and "f" orbitals;
- Understand reasons that there are exceptions to trends or be able to cite exceptions to trends (Students should realize, however, that there are exceptions to some of the trends);
- Understand periodic trends for atomic radius within a period, or other trends such as electronegativity, electron affinity, ionization energy, ionic radius or shielding effect.

Assessment Guidelines:

The objective of this indicator is to *explain* trends in atomic structure that are revealed by the periodic table, therefore, the primary focus of assessment should be to construct cause and effect models that show that if an element is found at a particular location on the periodic table, then certain characteristics of that element's atomic structure can be described relative to the other elements on the table. The cause-and-effect for this indicator only refers to knowing that an element has a certain position on the table because of its atomic structure. The reasons for the trends are beyond the scope of this course. Assessments should test the students' ability to apply this concept to any element or set of elements (other than those noted in the instructional guidelines as not essential). Assessment should not be restricted to memorized examples.

In addition to *explain*, assessments may require students to

- *Exemplify* trends on the periodic table;
- *Infer* some aspects of atomic structure of an element based on its position on the periodic table;
- *Compare* some aspects of atomic structure of two or more elements based on their relative positions on the periodic table.

Structure and Properties of Atoms

PS-2 The student will demonstrate an understanding of the structure and properties of atoms.

PS-2.4 Use the atomic number and the mass number to calculate the number of protons, neutrons, and/or electrons for a given isotope of an element.
Taxonomy Level: 3.2-C Understand Procedural Knowledge

Key Concepts:

Mass number
Atomic number

Previous/Future knowledge: Students have not been introduced to this concept prior to Physical Science. Indicators PS-2.1, PS-2.2 and PS-2.3 are prerequisite for this indicator. Students must have a firm grasp of atomic number, mass number and how each of the three subatomic particles contributes to these values. It is also essential that students can interpret the mass number and the atomic number from the symbol for an isotope of an element. When given the symbol of an element, students must be able to determine the element's number of protons and electrons from the periodic table (PS-2.3).

It is essential for students to

- Use a periodic table and the equation: mass number = number of protons + number of neutrons to perform the following calculations:
  - When given the symbol for an isotope of an element (which includes the element's symbol and the mass number of the isotope), determine the number of protons, neutrons, and electrons
    1. Determine the number of protons and the number of electrons from the periodic table
    2. Calculate the number of neutrons from the equation.
  - When given the mass number and the number of neutrons for a particular isotope of an unknown element, write the symbol for the isotope.
    1. Use the above equation to calculate the number of protons.
    2. Use the number of protons to determine the number of electrons, and the identity of the element
    3. Write the symbol for the isotope

$^{27}_{13}Al$ or Al-27 $^{238}_{92}U$ or U-238

Teacher note: The mass number cannot be determined by rounding off the atomic mass.

Assessment Guidelines:

The objective of this indicator is to *use* the correct procedure to mathematically determine the number of protons, neutrons, and/or electrons in an isotope of an element when given the mass number and the atomic number of the isotope, therefore, the primary focus of assessment should be to apply this procedure for any given element.

In addition to *use*, assessments may require students to

- *identify* of the element, the mass number, the atomic number, and the number of electrons when given the number of protons and neutrons.

Structure and Properties of Atoms

PS-2 The student will demonstrate an understanding of the structure and properties of atoms.

PS-2.5 Predict the charge that a representative element will acquire according to the arrangement of electrons in its outer energy level.
Taxonomy Level: 2.5-B Understand Conceptual Knowledge

Key Concepts:
Chemical stability: chemically stable atom, chemically unstable atom
Valence electrons
Chemical reaction
Compound
Ion

Previous/Future knowledge: Students have not studied subatomic particles prior to Physical Science, so this is the first experience students will have with the idea that the number of outer-level electrons determines the chemical stability of an atom, and that atoms tend to gain, lose, or share electrons in order to become chemically stable. Fundamental knowledge of the fact that some elements are chemically stable and do not react chemically, that most elements are not chemically stable and do react chemically and how atoms achieve a chemically stable situation with reference to outer-level electron arrangement of the atom is essential for all of the study of chemistry. As this is an introduction to the concept of ionization, emphasis should be placed on those groups of elements that are likely to gain or lose 1 or 2 electrons, and on the Noble Gasses.

It is essential for students to
- Understand that there are only a few *chemically stable* atoms. These are the Noble Gases. Understand that data shows that these stable atoms contain 8 valence electrons (or 2 for helium). Atoms that do not contain 8 valence electrons in the neutral state (when the number of electrons equals the number of protons) tend to gain, lose or share valence electrons in order to achieve stability.
  - All of the theory depends on the observable behavior that showed that there were some elements that did not undergo chemical change (normally).
- Understand that only electrons are involved in chemical reactions.
  - In chemical reactions, the number of protons and the number of neutrons remain constant.
- Determine (by using a periodic table) the number of protons and the number of electrons a neutral atom of a given element contains. (PS-2.3)
- Understand that atoms tend to lose, gain or share electrons to have the same number of *valence electrons* (electrons in the outer-most energy level) as one of the stable elements, i.e., the Noble Gases.
- Predict how many electrons an atom of a given element will gain or lose in order to most readily reach chemical stability based on the following generalizations:
  - The elements in group 18 are stable as they are with 2 or 8 electrons in the outer energy level and, therefore, do not gain or lose electrons except under extreme conditions.
  - The elements in groups 1 and 2 tend to lose 1 and 2 electrons respectively.
  - The elements in groups 16 and 17 tend to gain 2 and 1 electron respectively.
  - The elements in groups 13-15 are less likely than those listed above to either gain or lose electrons because they have 3, 4, and 5 valence electrons respectively. Students are **not**

responsible for predicting the charges of elements from groups 13-15 as these elements tend to share electrons rather than gain or lose electrons.
  - Most of the transition elements (groups 3-12) tend to lose electrons.
- Understand that if a neutral atom loses electrons, the particle formed will have a positive charge and if a neutral atom gains electrons, the particle formed will have a negative charge. The charged particle is called an *ion*.
  - Understand that the ion formed is chemically stable.
  - Reconcile the number of protons and electrons in the resulting ion and determine the excess positive or negative charge.
- Refine their definition of metals as elements that tend to lose electrons and non-metals as elements that tend to gain electrons. (Students distinguished metals from nonmetals by their position on the periodic table and their observable properties in 7th grade and in PS-2.3)
  - Students should be aware that some of the chemical properties of metals and nonmetals are due to their tendency to lose or gain electrons.

It is not essential for students to
- Understand reasons that there are exceptions to ionization trends or be able to cite exceptions to trends; (Students should, however, realize that there are exceptions.)
- Understand how the size of some elements influences whether they gain or lose electrons. (Metalloids)

Assessment Guidelines:
The objective of this indicator is for students to *predict* the charge that a representative element will acquire based on the number of electrons the element has in its outer-most energy level, therefore, the primary focus of assessment should be to show that students can use knowledge of chemical stability and the relationship between an element's position on the periodic table and outer-shell electron arrangement to predict whether an atom will gain or lose electrons, and how many electrons will be involved. Assessments should test the students' ability to infer the charge for the chemically stable ion formed from any element or set of elements (elements not mentioned in the instructional guidelines are not essential).

In addition to *predict*, assessments may require students to
- *Summarize* atomic properties that are a result of an atom's tendency to gain, lose, or share electrons;
- *Exemplify* elements that can form ions with like charges;
- *Interpret* diagrams that depict outer-shell electron arrangement;
- *Compare* charges of stable ions that are likely to form from elements within the same family and between families of representative elements.

PS-2.6 Compare fission and fusion (including the basic processes and the fact that both fission and fusion convert a fraction of the mass of interacting particles into energy and release a great amount of energy).
Taxonomy Level: 2.6-B Understand Conceptual Knowledge

Key Concepts:
Nuclear fission: chain reaction, critical mass
Nuclear fusion

Previous/Future knowledge: Students have not been introduced to fission and fusion prior to Physical Science. Students were introduced to nuclear decay in indicator PS-2.2. Fission and fusion are two very different nuclear reactions. Students often confuse chemical reactions with nuclear reactions. It is therefore essential that students understand the processes of nuclear reactions to the extent that they can differentiate them from chemical reactions, and also to understand the roles that nuclear processes have in global affairs (PS-2.7).

It is essential for students to
- Understand that nuclear reactions involve the particles in the nucleus of the atom (as opposed to chemical reactions, which involve the electrons in an atom and where the nucleus remains intact).
- Understand that there is a great deal more energy change involved in nuclear reactions than in chemical reactions.

Nuclear fission
- Understand the processes of *nuclear fission*
  - *Nuclear fission* occurs when a heavy nucleus, such as the U-235 nucleus, splits into two or more parts, a large amount of energy is released.
    - The absorption of a neutron by a large nucleus (such as U-235) is one way to initiate a fission reaction.
    - When an atom with a large nucleus undergoes fission, atoms that have smaller nuclei result. In the process smaller particles, such as neutrons, may be ejected from the splitting nucleus.
    - If one or more ejected neutrons strike another U-235 nucleus, another fission reaction may occur. The continuation of this process is called a *chain reaction*. There must be a certain minimum amount of mass, called a *critical mass,* of fissionable material in close proximity for a chain reaction to occur.
  - Understand that fission is the type of nuclear reaction that occurs in nuclear power plants and other nuclear applications (atomic bombs, nuclear-powered submarines and satellites).
  - Understand that the mass of the products of a fission reaction is less than the mass of the reactants.
    - This lost mass (m) is converted into energy (E). The equation $E = mc^2$ shows the relationship of this "lost mass" to the energy released. (It is **not** essential for students to use this equation.)
    - The conversion of mass to energy during a nuclear reaction involves far more energy than the amount of energy involved in a chemical reaction.

Structure and Properties of Atoms

PS-2 The student will demonstrate an understanding of the structure and properties of atoms.

Nuclear fusion

- Understand the processes of *nuclear fusion*
  - *Nuclear fusion* occurs when light nuclei (such as hydrogen) fuse, or combine, to form a larger single nucleus (such as helium).
  - As in fission reactions, in fusion reactions the mass of the products is less than the mass of the reactants and the "lost mass" is converted to energy.
  - Fusion is the type of nuclear reaction that occurs on the sun (and other stars).
  - Forcing small nuclei to fuse requires huge amounts of energy; however, when fusion reactions occur on the sun, more energy is released than the amount of energy required to produce the reaction.
  - Using fusion for nuclear power plants is still in the developmental stage.
  - A hydrogen bomb, also called a thermonuclear bomb, utilizes nuclear fusion.

It is not essential for students to

- Understand nuclear binding energy, or the dual nature of matter and energy;
- Use the equation $E = mc^2$ or explain the equation in any depth; (Students are generally familiar with the equation so mentioning it brings relevance to the concept.)
- Write or balance nuclear equations for fission or fusion nuclear reactions.

Assessment Guidelines:

The objective of this indicator is to *compare* fission and fusion, therefore, the major focus of the assessment should be to identify the similarities and differences in fission and fusion, the consequences, and the applications of the two processes.

In addition to *compare*, assessments may require students to

- *Exemplify* relevant uses of each process;
- *Classify* a process as either fission or fusion;
- *Summarize* major points about the steps in each process;
- *Illustrate* the process in a diagram format;
- *Recognize* each process from an illustration.

Structure and Properties of Atoms

PS-2 The student will demonstrate an understanding of the structure and properties of atoms.

PS-2.7 Explain the consequences that the use of nuclear applications (including medical technologies, nuclear power plants, and nuclear weapons) can have.
Technology Level: 2.7-B Understand Conceptual Knowledge

Key Concepts:

Nuclear medicine
Nuclear power reactors
Nuclear weapons

Previous/Future knowledge: Students were introduced to the process of nuclear decay in PS-2.2 and to fusion and fission in PS-2.6. PS-1.7 requires that Physical Science students can evaluate technology on the basis of designated criteria. As South Carolina is a major player in the United States nuclear program, it is important that students can understand and evaluate nuclear applications.

It is essential for students to understand that the term "consequences" refers to both those that are negative and those that are positive. They also need to understand that nuclear decay occurs naturally in many elements that are common on earth, and there is always some radiation present in every environment. The degree to which radiation is harmful to living organisms depends upon the type of radiation and the quantity of radiation to which the organism is exposed.

Students need to understand the identified nuclear applications in the indicator:

Nuclear medicine

Understand that radioactive materials are used in medical technologies.

- Examples of benefits might include:
  - Using radiation that results from the decay of certain isotopes to destroy targeted cells, such as cancer cells.
    - Cells are most susceptible to damage from radiation during the process of cell division. As cancer cells divide at a very fast rate, they are destroyed in greater numbers than normal cells, which divide less often.
  - Using the radiation that results from the decay of certain isotopes as a way of mapping the path of various substances through targeted organ systems.
    - Most substances that naturally pass through specific body systems can be "tagged" with radioactive samples of the same substances. The radioactivity can then be traced (using a Geiger counter, photographic film, or computers with "gamma cameras") as the "tagged" substance naturally makes its way through the targeted body system thus revealing how the body system is functioning. In this manner, the natural functioning of the body system can be observed.
- Examples of possible drawbacks might include:
  - Waste from nuclear medicine must be stored in a special way until it is no longer radioactive.
  - Radiation treatment directed at cancerous cells will also cause some damage to healthy tissue. Newer radiation treatments seek to minimize the damage to the healthy tissue while still destroying the cancerous tissue.

Nuclear weapons

Understand that some fission and fusion nuclear reactions can be used in weapons.

- Examples of benefits might include:
  - Some people believe that nuclear weapons are a deterrent to war.
- Examples of possible drawbacks might include:
  - Specialized technology is required to refine the fuel and to produce the weapons.
  - Tremendous amounts of energy available from small amounts of fuel so smuggling is possible.
  - The potential for a tremendous amount of destruction, both material and biological.
  - Contamination of the environment with fission-product isotopes, many of which are radioactive and remain so for very long periods of time.
  - Waste from the production of nuclear weapons must be stored in a special way until it is no longer radioactive, which can be a very long time.
  - Nuclear waste must be transported from where it is generated to where it will be stored, which very often involves passing through populated areas.
  - Improper handling of nuclear materials and possible leakage can cause radioactive isotopes to contaminate the environment, causing long-term radioactive decay problems.

Nuclear-power reactors

Understand how nuclear technology is used to produce electricity

- Energy from controlled nuclear fission is used to heat water into steam,
  - The steam expands turning a turbine which spins a huge magnet within a coil of metal wire
  - The moving magnetic field forces electrons to flow in the metal wire.
- The primary difference between a coal-powered electric generating plant and a nuclear-powered electric generating plant is the method of heating water; the other processes in the sub-bullets above are the same in both types of power plants (see PS-6.11 Generators).
- Examples of benefits might include:
  - Tremendous amounts of energy available from small amounts of fuel
  - No greenhouse gas or other air pollution from the burning of fossil fuels
  - Can be used anywhere (as opposed to wind power, solar power, hydroelectric power, etc)
  - Abundance of fuel
  - Non-reliance on fossil fuel
- Examples of possible drawbacks might include:
  - Requires specialized technology to refine the fuel.
  - Can cause thermal pollution to water systems.
  - Waste from nuclear fission reactors must be stored in a special way until it is no longer radioactive, which can be a very long time.
  - Nuclear waste must be transported from where it is generated to where it will be stored which very often involves passing through populated areas.
  - Improper handling of nuclear materials and possible leaks can cause radioactive isotopes to contaminate the environment, causing long-term radioactive decay problems.
  - Accidents in poorly designed or poorly maintained facilities, such as Chernobyl or Three Mile Island.
  - Exposure of workers in nuclear facilities to radiation.

Structure and Properties of Atoms

PS-2 The student will demonstrate an understanding of the structure and properties of atoms.

Assessment Guidelines:

The objective of this indicator is to *explain* consequences of nuclear applications, therefore, the primary focus of assessment should be to construct cause and effect models that show both the beneficial effects that the nuclear reaction has in meeting a need or producing a product and the possible drawbacks that might result from the process.−

In addition to *explain*, assessments may require students to

- *Exemplify* a nuclear application;
- *Summarize* major points about one of the applications listed;
- *Recognize* the benefits or drawbacks of nuclear power.